The Malawi Priorities Project

Cost benefit analysis of improving neonatal and maternal health outcomes in Malawi - Technical Report

National Planning Commission Report with technical assistance from the Copenhagen Consensus Center and the African Institute for Development Policy

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1. Introduction

Malawi has been one of the few low-income countries to achieve the Millennium Development Goal (MDG) for child survival (Kanyuka et al, 2016). The country is rightly considered a global success story in this area, given its wealth and resource constraints. Malawi has reduced under-5 mortality by two-thirds between 1990 and 2015 from 234 deaths to 63 deaths per 1000 live births in 2015–16. This has been achieved by a series of community level interventions to address the major causes of child death and includes vaccinations drives, bed nets, supplementary nutrition programs, diarrhea and malaria treatment and prevention and treatment of HIV (Kanyuka et al, 2016). The rate has now further reduced to 50 deaths per 1000 live births (UNICEF, 2019) representing a 78% decrease over a 28-year period. This achievement is proof of the country's high-level policy commitment to child health, and support for strengthening health workforce capacity, and expanded maternal and newborn care (Dickson et al, 2014).

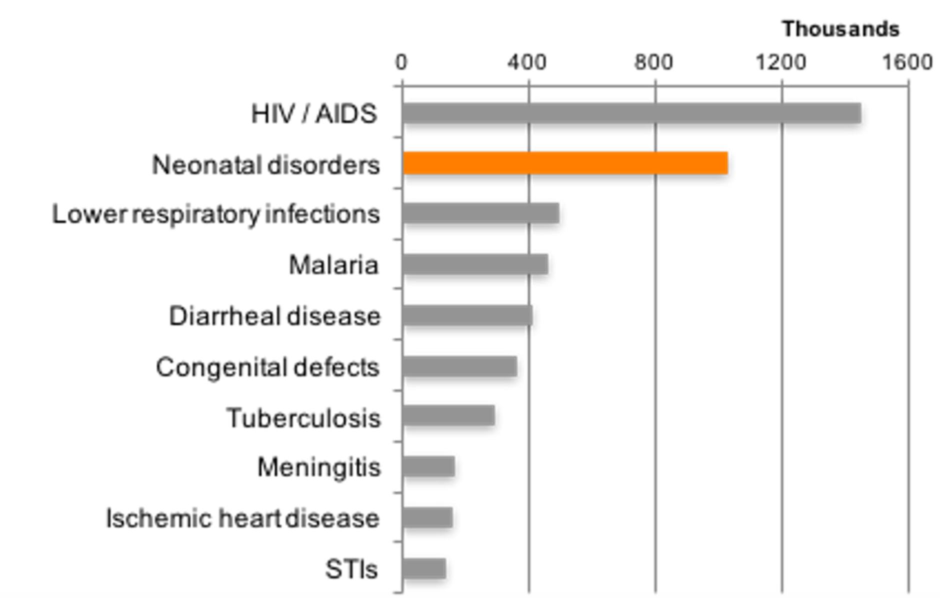
However, while child mortality has decreased substantially for all age groups above age 1, the rate of decline of neonatal mortality has been slower even though rates of facility births are increasing (MDHS, 2017). While child mortality declined by more than 5% annually from 2000, neonatal mortality declined less rapidly (3.3% per year) from 50 in 1990 to 22 deaths per 1000 births in 2018 (UNICEF, 2019). In 2017, neonatal disorders represented the second highest source of disability adjusted life years (DALYs) after HIV / AIDS (Figure 1).[1] Malawi also faces a challenge with maternal mortality, with the country recording among the highest maternal mortality rates in the world.

What is evident therefore is that in the broad area of maternal, neonatal and child health, Malawi has performed well in the area of child health, but needs to address maternal and neonatal health as a high priority. To achieve this, investments in interventions to improve reproductive, maternal and newborn health are crucial. Of the overall 2.9 billion U.S. dollars budget for the country's 2020/2021 financial year, the health sector was allocated 273.5 million U.S. dollars, around 11.5% of the total budget and 2.9% of GDP. While this represents an increase from the 7.2% of GDP spent on health in 2011, it still does not meet the Abuja Declaration target for African States of allocating 15% of total government expenditure to the health sector (Abuja Declaration, 2001).

1.2 Causes of Neonatal and Maternal Mortality

The leading causes of neonatal mortality in Malawi are intrapartum related events (26%) preterm birth complications (33%), and sepsis (19%) (UNICEF, 2015) Globally, Malawi has the highest rate of preterm birth at 18%, which contributes substantially to

***Figure 1:** Top Causes of Disability Adjusted Life Years (DALYs), 2017*

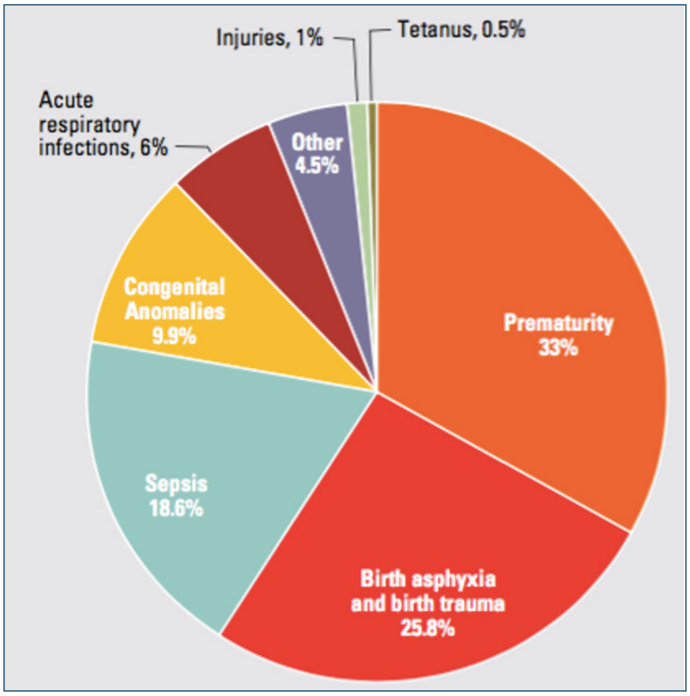


Source: Institute for Health Metrics and Evaluation, (2019)

[1] As this report was being finalized, updated data from the Global Burden of Disease was released which showed that in 2019 neonatal disorders had overtaken HIV and AIDS as the number 1 cause of disabil-ity adjusted life years in the country

neonatal mortality risk (Katz et al., 2013). The most common direct causes of maternal death are hemorrhages, eclampsia, obstructed labor and abortions. In Malawi's rural facilities, sepsis, hemorrhage, eclampsia and obstruction account for 32%, 32%, 20% and 11% of obstetric complications, respectively, while other direct/indirect causes account for the remaining 5% (van den Akker et al, 2011).

Figure 2: *Causes of Neonatal Mortality in Malawi*



Source: UNICEF (2015)

While the underlying drivers of neonatal and maternal mortality are complex and interdependent, two opportunities appear to be particularly promising in addressing these related challenges. The first opportunity relates to the quality of care in health facilities offering delivery services. Facility delivery rates have increased from 53% in 2000 to 90% in 2014, most likely as a result of a 2007 ban on deliveries with traditional birth attendants (Godlonton and Okeke, 2016). However, facility-based births have not led to as much improvements in neonatal and maternal mortality as expected with many of these facilities remaining understaffed as well as lacking key medicines and equipment (Mazalale et al, 2015, Mgawadere et al., 2017). According to the Malawi Service Provision Assessment 2013-14 (Ministry of Health [Malawi] and ICF, 2014) facilities at all levels lack signal functions for emergency obstetric and newborn care, with health centers and clinics faring worse than hospitals (see Figure 3). For example, less than 50% of health centers offered anticonvulsants, assisted vaginal delivery, manual removal of placenta and removal of retained products of conception. This is particularly important given that 56% of all births occurred in health centers (National Statistical Office [Malawi] and ICF, 2017).

1.3 Reducing Maternal and Neonatal Mortality

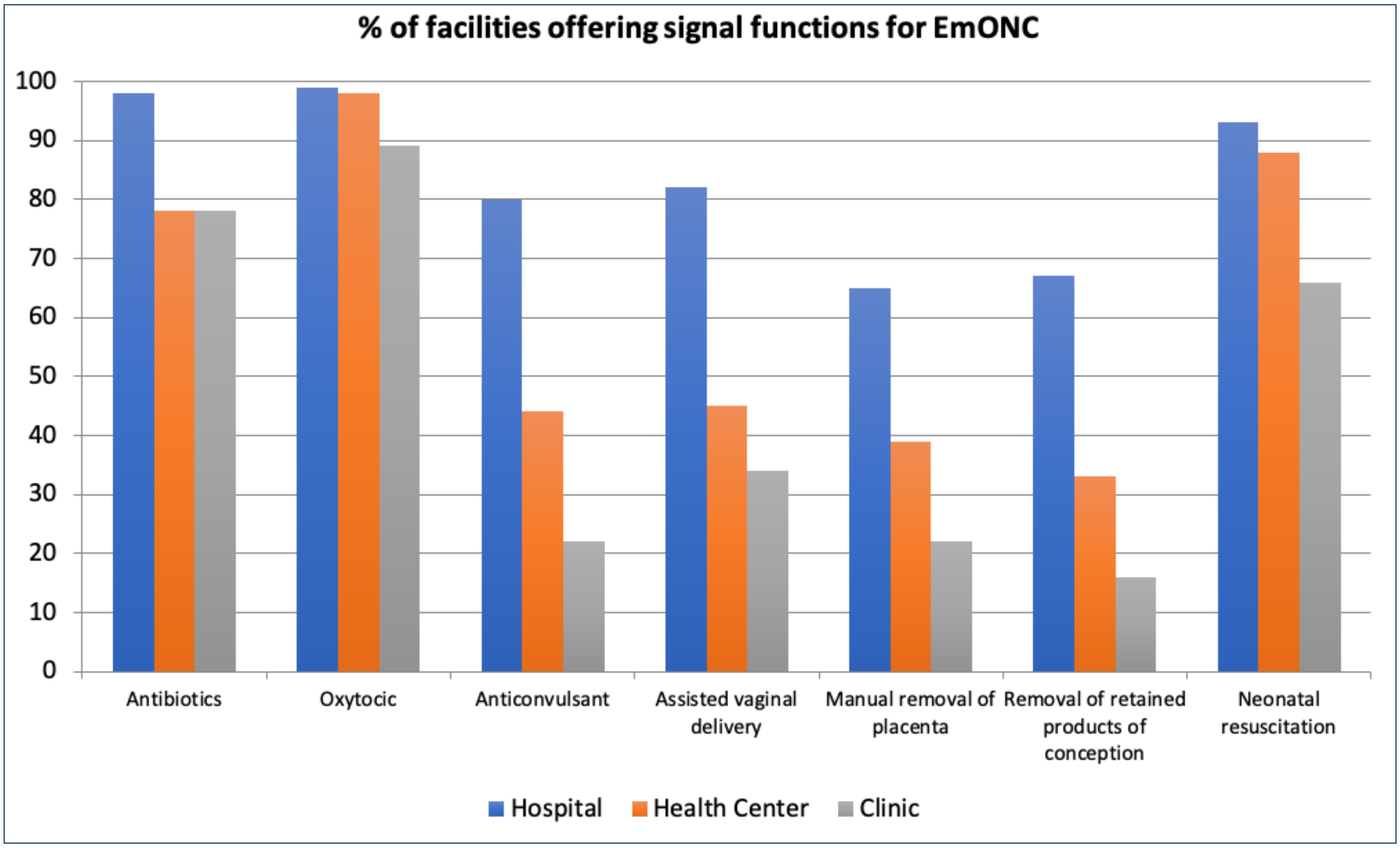
Ensuring survival of mother and baby depends in large part on rapid and competent care during labor and delivery in most low-income countries (Dickson et al, 2014). For example, basic neonatal resuscitation could avert as many as 30% of intrapartum-related newborn deaths in low resource settings (Wall et al, 2009). An estimated 40% of global deaths due to sepsis and tetanus could be prevented with infection control and hygienic cord care (Blencowe et al, 2011), and kangaroo mother care for low birth weight (LBW) infants should reduce neonatal mortality in these high-risk babies by half in high burden countries (Bhutta et al, 2011). Interventions that can prevent maternal mortality include parenteral administration of antibiotics, maternal sepsis management, antibiotics for preterm or prolonged PRoM (Premature Rupture of Membranes), and a clean birth environment (Pollard et al 2013). All of these interventions require qualified health workers as well as facility infrastructure and resources (Das et al, 2014).

Under the HSSP I Malawi made substantial health gains. HSSP I targets for Under-5 mortality and infant mortality were surpassed. The target for Under-5 mortality in HSSP 1 was 78/1000 live births and for infant mortality was 45/1000 live births by 2015-2016. However, U-5 mortality was reduced to 63/1000 live births and infant mortality to 42/1000 live births. These gains in health outcomes could partially be attributed to increased utilization of some key services such as skilled attendance at birth which was estimated at 90% in 2016 and the percentage of pregnant women making at least one ANC visit during pregnancy was 95%. On the other hand, only 24% of pregnant women had their first ANC visit in the first trimester; only 51% had four or more ANC visits and only 42% of women and 60% of new-borns received a postnatal check 48 hours of birth (DHS 2015-16).

While it is encouraging that almost all women in Malawi deliver at a health facility, simply delivering there does not guarantee care of sufficient quality to prevent newborn or maternal deaths (Knight et al, 2013; Mgawadere et al., 2017). A recent meta-analysis of 192 Demographic and Health Surveys (DHS) found inconsistent links between institutional delivery coverage and neonatal mortality (Fink et al, 2015). Similarly, case studies in Rwanda and Malawi found no evidence of decreased neonatal mortality following large increases in facility-based delivery (Okeke and Chari, 2014). Therefore, improving the provision of emergency obstetric and newborn care appears to be critical for reducing neonatal and maternal mortality in the country.

The second area of opportunity relates to the nutrition status of pregnant women. A relatively low proportion – 7% - of (non-pregnant) women aged 15 to 49 are classed as underweight (BMI of less than 18.5) although the figure rises to 13% in the 15-19 age group, when child-bearing begins for many women. The percentage underweight has decreased to some extent, but levels of overweight and

Figure 3: Percentage of Facilities Offering Signal Functions for BEmONC (Basic Emergency Obstetric and Newborn Care)



Source: Malawi Service Provision Assessment (2013-14)

obesity have increased from 17% in 2010 to 21% in 2015-16. 13% of women were overweight and 4% obese according to DHS, 2010. This increased to 15% of women being overweight and 6% obese according to DHS, 2015-16. (DHS, Malawi, 2010 & 2016). 45% of pregnant women in Malawi suffer from anaemia. Of these, 22.7% suffer from a mild form, 20.8% from moderate and about 2% from a severe form of anaemia (DHS, 2015-16).

The Micronutrient survey (2015-16) indicates that levels of iron deficiency, anaemia, and iron deficiency anaemia among pregnant women were 25%, 45%, and 23% respectively. The prevalence of low retinol binding protein as a proxy for vitamin A status was 15% among pregnant women, while prevalence of zinc deficiency was 37%. Serum folate deficiency, indicating risk of megaloblastic anaemia, was 0.2% and red blood cell folate insufficiency, indicating risk of neural tube defects, was 46% among pregnant women. Approximately half (53%) of pregnant women had evidence of vitamin B12 depletion, and 9% of pregnant women were vitamin B12 deficient (NSO et al. 2017).

Maternal undernutrition is associated with elevated maternal mortality (Diana et al, 2020). Poor maternal nutrition is associated with a raft of suboptimal birth outcomes including low birth weight and prematurity (Broek, Jean-Baptiste and Neilson, 2014). Prematurity appears particularly problematic with Malawi having the highest rate of preterm birth globally at 18% (Blencowe et al, 2011). Being born prematurely is associated with a 6.8 times higher risk of mortality in the first 30 days compared to normal gestation, (Katz et al., 2013) and surely contributes to poor neonatal mortality outcomes in Malawi.

Nutrition supplements, such as multiple micronutrients and calcium, taken during pregnancy have been shown to improve maternal and birth outcomes. For example, calcium supplementation has also been shown to reduce prematurity risk with a relative risk of 0.88 across 10 randomized controlled trials (Imdad, Jabeen and Bhutta, 2011). It also reduces maternal deaths from hypertensive disorders by 20% (Ronsmans and Campbell, 2011). Smith et al., (2017) analyze 17 randomized control trials involving 112,953 women and note an 8% reduction in prematurity when taking multiple micronutrients (MMN). They also show, among other results, that maternal weight as measured by body-mass index (BMI) is the most important modifier for this effect with underweight mothers benefitting by a 16% lower risk of prematurity compared to 6% for non-underweight mothers. Evidence shows that MMN also reduces the incidence of stillbirths by 9% (Haider and Bhutta, 2015), Providing these supplements to ameliorate nutrition deficiencies in pregnant women appears to be another promising avenue to address neonatal and maternal deaths.

This technical report outlines the costs and benefits of various strategies to improve Emergency Obstetric and Newborn Care (EmONC) and deliver nutrition supplements to women in pregnancy with the ultimate aim of reducing neonatal and maternal mortality. In particular we assess several different interventions:

1. A full package of 15 different Basic Emergency Obstetric and Newborn Care (BEmONC) interventions scaled up to 90% of health facilities, including adequate back up electricity
2. A targeted package of 5 BEmONC interventions addressing the largest causes of neonatal mortality scaled up to 90% of health facilities, including adequate back up electricity
3. Individual neonatal mortality interventions scaled up to 90% of health facilities:
    a. Clean birth practices
    b. Kangaroo mother care
    c. Hygienic cord care
    d. Assisted vaginal delivery
    e. Neonatal resuscitation
4. Replacing iron and folic acid (IFA) with multiple micronutrient supplements (MMN) delivered during antenatal care (ANC) visits
5. Providing calcium supplements during ANC visits
6. Providing MMN and calcium supplements during ANC visits

These interventions were chosen based on a number of criteria including demonstrated cost-effectiveness or large BCRs in previous literature as well as an ability to address a large driver of neonatal or maternal mortality (see Section 2 for detailed discussion of intervention selection process). We use the Lives Saved Tool (LiST) to estimate the impact on maternal and neonatal mortality as well as related birth outcomes from the scale up of these interventions. Developed and maintained by John Hopkins University and Avenir Health, LiST is a commonly used application to estimate maternal and child health outcomes from the scale up of various interventions.

An important contribution of this paper is the attempt to not just focus on the relatively easier narrative of scaling up of variable costs with respect to equipment and personnel, but also include the more holistic and harder to estimate costs that are required to enable these interventions to address the specific challenges in Malawi. The paper incorporates a training cost – based on a study from Ghana (Willcox et al; 2017) that uses a mentorship style program as compared to a traditional offsite training program. It also focuses on building in electricity costs as erratic power supply is one area which is potentially a huge constraint to providing better healthcare and maternal care services.

With regard to supply chain management, the analysis factors in a simple adjustment that increases the one-time available inventory so that there is a buffer stock available to reduce likelihood of stock outs of essential medicines and consumables. We acknowledge that broader supply chain reform is essential in Malawi but this restructuring and overhaul of the supply chain would be better considered in the context of the entire health system and not just for BEmONC supplies. Therefore, this broader supply chain reform is considered out of scope for this paper. However, studies conducted in Sudan by Makawi et al (2020) and the systematic review of Seidman and Atun, (2017) note that health supply chain reform is likely to yield net benefits in terms of reduction in unit costs of supply. If this were to be included any additional costs from reform would likely be offset by reduced costs of procuring and delivering essential medicines and consumables, leading to larger benefit-cost ratios than what is reported in this paper.

Our results indicate that many of these interventions would be a very good or excellent use of resources in Malawi. Of the interventions focusing on improving services at health facilities, the targeted package has a very high BCR of 31 at an 8% discount rate. With the exception of kangaroo mother care, the interventions scaled up individually would not deliver as large an impact in terms of avoided mortality and have similar or lower BCRs as the targeted package. This is due to the presence of economies of scale in health training and electricity provision when a package of interventions is delivered that more than offset redundancy and overlap in benefits from delivering multiple interventions. Kangaroo mother care as a stand-alone intervention has the highest BCR of 45 because we assume it does not require electricity to implement. The full package of 15 BEmONC interventions also has a quite large BCR of 15, but this is mostly driven by the five interventions in the targeted package, which yields about 85% of the benefits of the full package. Therefore, the incremental efficiency of the extra 10 interventions is relatively limited with a BCR of 4. Replacing IFA with MMN has the largest BCR of the nutrition interventions at 14, while calcium supplementation has substantially lower BCRs.

Our results suggest that policy makers should ensure that health workers can adequately provide a package of five interventions, namely kangaroo mother care, assisted vaginal delivery, hygienic cord care, neonatal resuscitation and clean birth environments. To enable these interventions would require the presence of health workers trained in appropriate basic emergency obstetric and newborn care procedures (BEmONC). This constraint appears to be the biggest challenge and represents the greatest cost in delivering the interventions. The greatest number of appropriately trained staff are in the hospital sector, with 285 across 95 individual sites. However, this is only 12% of the personnel employed. There are many more health centers (414) plus 19 clinics, but together these have fewer medical staff than in hospitals and an even lower percentage trained in BEmONC. Training more staff not only has a significant direct cost, but also takes them away from patient care for ten days. If the majority of staff can be trained, it makes it more likely that one or more doctors or nurses would be available to deliver the necessary care to mothers and babies. However, there clearly need to be sufficient staff to deliver both these services and address all the other healthcare issues each facility has to deal with. Additional requirements include the availability of backup electricity, medical disinfectants (e.g. chlorhexidine) and certain equipment such as resuscitation bags, forceps and autoclaves. However these appear to be less challenging to implement than the human resource constraint.

The upfront cost of the targeted BeMONC package in Malawian Kwacha (MWK) is MWK 11,812 million with training representing just over half the cost. In 2021-2022, the cost is around MWK 2,125 every two years rising to MWK 2,574 million every two years by 2034-2035. The recurrent costs are predominantly staff time and bi-annual training. The intervention would avoid around 2,000 neonatal deaths, 110 maternal deaths and 1,800 intra-partum still births in 2021, with these figures rising in line with expected increase in deliveries over time.

Replacing IFA supplements given to pregnant women during ANC visits with MMN supplements, should be prioritized after the targeted BeMONC package. Calcium supplementation should not be prioritized due to the relatively high cost of the tablets. The MMN intervention would require around MWK 600 million per year in additional investment beyond what is already been paid for IFA tablets. It would also require upfront investment of MWK 2,157 million in planning, coordination and behavioral change. Over five years we expect these costs to reduce to zero (relative to counterfactual) as MMN becomes normalized as part of providing routine ANC. The MMN intervention would avoid around 430 neonatal deaths and 900 stillbirths in 2021, rising over time to reflect increase in expected births. For the MMN intervention, we do not envisage significant constraints to scale up since 90% of women are already attending ANC and taking some form of iron tablets. Additionally, the Malawian health system is already operationalized to deliver IFA and it does not seem too large a leap to swap this with MMN. On this account, the MMN intervention perhaps has a smoother implementation pathway than BeMONC.

2. Research context and intervention selection process

The National Planning Commission (NPC), Malawi, in collaboration with the African Institute for Development Policy (AFIDEP), and the Copenhagen Consensus Center (CCC) have started the Malawi Priorities project – a research and advocacy exercise to identify the most effective ways to address the nation's challenges using the framework of cost-benefit analysis. The aim is to inform both short- and long-term development priorities for the country, acknowledging that there are insufficient resources to address all of Malawi's challenges and that maximizing outcomes requires careful, evidence-based consideration of the costs and benefits of all policies.

The starting point of all research questions is the NPC's existing research agenda, structured around the six thematic areas of Sustainable Agriculture, Sustainable Economic Development, Human Capital and Social Development, Sustainable Environment, Demography, Governance, Peace, and Security, and Human Capital and Social Development.

NPC's research agenda was developed by in September 2019 after extensive consultation with academics, think tanks, the private sector and government. Consequently, the commission's research agenda, prima facie, contains questions of national importance. As a first step, Malawi Priorities drew questions from the NPC research agenda that could be answered by Cost-benefit analysis (CBA). Then, additional research questions were added based on input from NPC, an Academic Advisory Group (AAG) of leading scholars within Malawi, and existing literature, particularly previous cost-benefit analyses conducted by the Copenhagen Consensus Center. This process of identifying research questions for investigation generated a total of 38 potential research questions across all 6 thematic areas.

The research agenda was validated and prioritized by a Reference Group of 25 prominent, senior stakeholders from government, civil society and the private sector. The outcomes of the Reference Group exercise were used to inform which research questions to prioritize and which interventions to focus on within those research questions. The validation process finished in July 2020.

The intervention selection process started with a wide universe of potential interventions. For this particular paper we started with the potential interventions provided in the Lives Saved Tool (LiST) – more than 30 individual interventions impacting maternal and neonatal mortality. We also interviewed several local experts, including:

- Charles Mwansambo, *then Chief of Health Services in the Ministry of Health and Population, now Principal Secretary in the Ministry of Health*
- Vandana Stapleton, *USAID*
- Reuben Ligowe, *USAID*
- Chifundo Kuyeli, *USAID*
- Malawi Priorities reference group

Though there is no mechanical formula for selecting interventions, several important factors include:

1. **Sector expert priority** – An intervention is accorded higher priority if sector experts note that it is important. There are several avenues from which experts provide input into our process such as the Reference Group questionnaire, direct interview, inferences from the NPC research agenda, and via our academic advisory group.
2. **High benefit-cost ratio or cost-effectiveness in similar previous research** – The purpose of the Malawi Priorities project is ultimately to identify interventions of outsized benefits relative to costs. Input into this factor is determined from the economics literature, particularly previous research conducted by the Copenhagen Consensus Center. In the Center's experience BCRs above 15 are among the highest across all interventions. Due consideration is given to contextual differences between previous research and the current situation in Malawi in determining the effect of this criterion.
3. **Addresses a problem of sufficient size** – some interventions could be considered highly effective but only address a small percentage of a given problem, limiting the overall net benefits of the approach. To avoid focusing on solutions that are too small, each intervention must have the potential to address a problem that is significant as assessed against objective criteria (e.g. government reports and surveys, Global Burden of Disease)
4. **Significant gap in current coverage levels of intervention** – all analysis conducted in Malawi Priorities focuses on marginal benefits and costs. Therefore, if an intervention already has high coverage rates, then additional resources provided towards that

intervention are unlikely to be effective, or will suffer from the 'small-size' problem.

5. **Availability of crucial data or credible knowledge of impact** – due to time and resource constraints, all analyses conducted by *Malawi Priorities* are based on secondary data. No primary research is conducted, such as field experiments or trials. Therefore, each intervention is constrained by the availability of data. In many cases, one key constraint is knowledge concerning the impact of a given intervention. It is typical to formally deal with uncertainty via sensitivity analyses. However, in some cases the uncertainty is so great that it precludes even researching the intervention at all.

A forthcoming paper that examines the costs and benefits of scaling up maternal and neonatal health interventions across 59 LMICs was the starting point for screening interventions for further investigations in Malawi (Friberg et al. 2020).

That paper notes that a package of *basic emergency obstetric care* (BEmONC) either by itself or with family planning services has the largest potential, in terms of benefits relative to costs, for addressing maternal and neonatal mortality. We start by considering a similar package of BEmONC interventions in Malawi. The package includes 15 interventions within LiST (see Section 3 for further details). Our analytical strategy is to consider all of them as a package and then isolate several interventions to be considered as a targeted package and individually, based on their contribution to benefits. We do not consider family planning as there is a separate paper within the *Malawi Priorities* series examining this area.

Additionally, we investigate individual ANC interventions that appear to have high potential of addressing maternal and neonatal health. These individual interventions are multiple micronutrient supplementation in pregnancy and calcium supplementation in pregnancy. Previous Copenhagen Consensus research notes that the combination of these two delivered during ANC have high BCRs (Aryeetey et al. 2020; Joe et al. 2019). Here we consider them separately as well as together. Lastly, we look to Friberg et al. (2020) for individual interventions delivered during ANC that have large BCRs across 59 countries and note tetanus toxoid injection as the most promising intervention. However, tetanus toxoid is already scaled up to quite a high level in Malawi with 73% of women receiving two injections and 90% of births protected against neonatal tetanus (National Statistical Office [Malawi] and ICF, 2017).

The process of screening and prioritizing interventions is summarized in Table 1, drawing on the factors described above.

***Table 1:** Intervention Screening Process*

Intervention considered	Sector expert priority	High BCR or cost-effectiveness	Addresses a problem of sufficient size	Significant gap in current coverage levels	Availability of data	Overall
Multiple Micronutrient supplementation in pregnancy	Yes, poor nutritional quality of diet noted by sector experts.	Previous research from CCC indicates high BCRs of around 37 to 39 (India) and 18 in Ghana.	42% pregnant women, 34% women of reproductive age suffer from some degree of anemia.	Yes, though 90% of pregnant women received antenatal iron supplementation, there is no coverage of MMN supplementation.	Yes	High
Calcium supplementation in pregnancy	Yes, poor nutritional quality of diet noted by sector experts.	Previous research from CCC indicates BCR between 8 and 19.	Insufficient calcium during pregnancy is linked to the development of hyperten-sion, which is a leading cause of fetal growth restriction and preterm birth. 49% of population has inadequate dietary calcium.	Yes, though 90% of pregnant women received antenatal iron supplementation, there is no coverage of calcium supplementation.	Yes	High
BEmONC package of 15 interventions	Yes, importance of BEmONC interventions noted by sector experts	A forthcoming study of 59 LMIC notes a BEmONC package has a BCR around 70.	Yes, neonatal is high at 22 per 1000 births. Maternal mortal-ity is also very high at 459 per 100,000 births	Yes, BEmONC capability is reasonable at hospitals but is severely lacking at health centers	Yes	High
Individual interventions within the BEmONC package	Individual interventions were not typically mentioned in sector expert interviews, with a broader focus on packages on interventions	Component analysis identified five interventions that drove the majority of benefits from the larger package.	Yes	Yes	Yes	High

3. Cost benefit analysis

General parameters and assumptions

As with all analyses in the Malawi Priorities series we adopt three different discount rates: 5%, 8% and 14%. All figures are reported in 2020 Malawian Kwacha (MWK) unless otherwise indicated. The Gross Domestic Product (GDP) in 2020 is projected to be MWK 6.6 billion, with a COVID-influenced 2% growth rate for 2020 based on analysis undertaken by the World Bank (World Bank, 2020). Projections for the next years are 3.3%, 4.0%, 5.0%. Thereafter, projections use the growth rates implied by GDP estimates in the IIASA database as discussed in Riahi et al. (2017). We use the SSP2 scenario and median estimate by Organisation for Economic Co-operation and Development (OECD) and the International Institute for Applied Systems Analysis (IIASA). Growth figures are only provided every 5 years, so we assume a constant growth rate figure per 5-year period.

Mortality benefits are monetized as per standard Malawi Priorities protocol, which follow the *Guidelines for the Conduct of Benefit-Cost Analysis in Global Health and Development* (Robinson et al. 2019, see appendix to this document for further detail). Specifically, each neonatal death avoided is assumed to save 64.1 years of life, each maternal death avoided is assumed to save 46.7 years of life and each life year saved is valued at 0.6x GDP per capita in 2021, growing in line with projected income with an elasticity of 1.5.

We monetize low birth weight and stunting cases avoided by estimating the avoided productivity loss from each. Behrman and Alderman (2004) indicate that avoided low birth weight leads to a reduction in lifetime earnings of 7.5%. For avoided stunting we apply 30% boost to lifetime income. This is based on a survey of nine longitudinal studies of stunted children from LMICs which shows that avoiding stunting is associated with a 6cm increase in height in adulthood or adolescence (Gallaso and Wagstaff, 2016) and a review of thirteen studies that shows that 1cm of height is associated with 5% increase in wages (4% increase in wages for men, and 6% increase in wages for women, controlling for confounding factors; McGovern et al. 2017). Applying these figures, we estimate that in 2021, an avoided case of low birth weight leads to lifetime earnings gain of MWK 380,000 while the equivalent value for an avoided case of stunting is MWK 1,255,000 at an 8% discount rate.

Lastly, we value stillbirths as the avoided healthcare provider and patient costs associated with the stillbirth, including the cost of increased complications for the birth and an additional pregnancy. A study by Heazell et al (2016) suggests that care costs for stillbirths were 10–70% greater than with a live birth and we use the midpoint of 40% to estimate the increase in costs associated with a still birth. We use the costs of births from a study by Levin et al (2003) which tabulates the breakup of costs per ANC visit and per delivery in Malawi at both a public hospital as well as a public health centre.

We also identify additional patient costs from a study by Chinkhumba et al. (2020). We then value the loss of productivity of a still birth on the assumption that fathers take 3 days off and mothers take 10 days off after a stillbirth. We value the lost productivity at average income across Malawi. We also add the cost of additional pregnancy assuming that people who suffer a still birth are likely to replace the child and incur additional pregnancy costs. These costs are taken from Levin et al (2003). The total costs of avoided stillbirth are relatively minor and equate to approximately MWK 93,000.

4. Basic Emergency Obstetric and Newborn Care (BEmONC) for reduction of neonatal and maternal mortality

4.1 Interventions

In this section we conduct a cost-benefit analysis of "Basic Emergency Obstetric and Newborn Care" (BEmONC) interventions for reduction of neonatal mortality.

We do this for:

1. A full package of 15 BEmONC interventions;
2. A targeted package of 5 BEmONC interventions; and
3. Individual BEmONC interventions.

More details about all the interventions are given in Appendix 2.

The full package of BEmONC that we assess consists of 15 interventions. Five of these interventions are included in the targeted package, each of which is also assessed individually.

The intervention target is that 90% of health facilities providing normal delivery services will be fully equipped to provide BEmONC services. Benefits and costs are assessed from 2020 to 2035.

The analysis utilizes three main resources for estimating benefit-cost ratios (BCRs) of interventions:

1. The Malawi Service Provision Assessment (SPA) 2013-2014 survey;
2. Intervention unit input costs; and
3. The Lives Saved Tool (LiST).

The Malawi SPA 2013-14 is a large-scale systematic census survey and assessment of health facilities in the country. The SPA surveyed all 1060 formal facilities in Malawi at the time of the survey, of which 528 facilities offered normal delivery services (NDSs) accounting for 93% of all births with the largest share at health centers (Table 2).

Each of the 15 BEmONC interventions has specific input requirements in terms of supplies, medicines, and equipment. We obtained

Table 2: *Health facilities and deliveries in Malawi, 2013-14*

	Total facilities	Facilities Offering NDS*	PoD**
Hospitals	119	95	34%
Health centers	489	414	56%
Clinics	369	19	3%
Dispensaries	55	0	
Health posts	28	0	
	1060	528	93%

** NDS=normal delivery services. ** PoD=Place of delivery (% of all births). Source: The Malawi SPA report.*

the availability of these inputs at the health facilities from the SPA data and survey report along the lines of Chou et al (2019) in their modeling of neonatal and maternal health outcomes from effective delivery of a package of health services in 81 low- and middle-income countries using LiST. The specific inputs (indicators) required for each intervention are presented in Chou et al for a large subset of interventions in our BEmONC package.

The availability of required inputs serves as the baseline coverage rates of interventions, again as in Chou et al. (2019). The baseline coverage rates are used for estimating the costs of reaching the intervention target of 90% availability. Availability was highest at hospitals followed by health centers and lowest at clinics. Availability, or baseline coverage rates, are already at 90% or more for four of the interventions (Table 3). Marginal cost for these interventions will therefore be zero (Table 5).

As these data are from 6-7 years ago, coverage rates may be somewhat different in Malawi today. While this will affect estimates of total costs and benefits of reaching the 90% coverage target at each type of facilities, the magnitude of the benefit-cost ratios are not likely to be much affected.

Table 3: *Intervention baseline coverage rates at facilities providing normal delivery services*

	Hospitals	Health Centers	Clinics
1. Clean birth practices	61%	20%	22%
2. Neonatal resuscitation	82%	53%	33%
3. Antibiotics for PRoM	55%	38%	50%
4. Active management of third stage labor	61%	33%	27%
5. Induction of labor lasting 41+ weeks	98%	93%	83%
6. Hygienic cord care	51%	32%	39%
7. Thermal care for premature babies	100%	99.8%	100%
8. Kangaroo Mother Care (KMC) for premature babies	85%	50%	44%
9. Case management of neonatal sepsis with antibiotics	100%	96%	94%
10. Manual removal of placenta	69%	39%	22%
11. Immediate drying and newborn stimulation	100%	100%	100%
12. Parenteral admin of anticonvulsants	80%	44%	22%
13. Parenteral admin of antibiotics	98%	78%	78%
14. Assisted vaginal delivery	82%	45%	34%
15. Removal of retained products of conception	67%	33%	16%

Source: Estimates from the Malawi SPA data

4.2 Costs

Five categories of costs of the interventions are estimated:

1. annual recurrent cost (supplies, medicines, personnel);
2. electricity to facilities without regular supply;
3. equipment required to perform BEmONC services; and
4. BEmONC training of personnel

5. Improved supply chain management costs

4.2.1 Annual recurrent cost:

Recurrent costs were calculated using bottom-up costing, with detailed lists drawn up detailing the needs for drugs, supplies and medical staff time required per case for each of the interventions. Treatment was based on most recent WHO guidelines (WHO, 2017; WHO, 2015). Drugs, supplies and equipment were costed based on prices in the UNICEF supply catalogue (UNICEF, 2020). For each intervention, the types of medical staff and time required to provide the intervention were estimated and then multiplied by country-specific salaries, taken from WHO's CHOICE database (WHO, 2020a). The costliest interventions per delivery are parenteral administration of antibiotics (to treat maternal sepsis), management of eclampsia (parenteral administration of anticonvulsants), and removal of retained products of conception. These interventions are, however, only applied to 0.25-2.5% of deliveries. The least costly interventions per delivery are immediate drying and newborn stimulation, hygienic cord care, active management of third stage labor, thermal care for premature babies, Kangaroo Mother Care (KMC) for premature babies, and clean birth practices. Most of these interventions are applied to all deliveries, except for those pertaining to premature births (Table 4).

Unit costs are multiplied by the annual number of deliveries benefiting from the interventions and by the applicability rates to arrive at annual recurrent cost of interventions. Total annual recurrent cost for the 15 interventions of the full BEmONC package is MWK 11,580 million. This cost increases annually to 2035 at the rate of growth in annual deliveries, assuming constant real unit input costs over this

Table 4: Annual recurrent cost of interventions for the Full BEmONC package

	Cost per delivery		Beneficiary deliveries	Applicability rate *	Total cost, MWK million
	US$	MWK	Year 2021		Year 2021
1. Clean birth practices	1.05	780	320,591	100.0%	250
2. Neonatal resuscitation	3.57	2,658	153,495	5.0%	20
3. Antibiotics for PRoM	7.37	5,491	266,426	18.1%	265
4. Active management of third stage labor	0.51	376	272,288	100.0%	102
5. Induction of labor lasting 41+ weeks	2.62	1,949	0	5.0%	0
6. Hygienic cord care	0.41	308	298,342	100.0%	92
7. Thermal care for premature babies	1.00	745	0	18.1%	0
8. Kangaroo Mother Care (KMC) for premature babies	1.03	764	157,278	18.1%	22
9. Case management of neonatal sepsis with antibiotics	7.51	5,597	0	1.0%	0
10. Manual removal of placenta	17.06	12,708	233,381	2.0%	59
11. Immediate drying and newborn stimu-lation	0.26	197	0	100.0%	0
12. Parenteral admin of anticonvulsants	72.71	54,167	190,619	0.25%	26
13. Parenteral admin of antibiotics	105.4	78,556	43,926	2.5%	86
14. Assisted vaginal delivery	15.18	11,308	182,511	5.0%	103
15. Removal of retained products of conception	50.93	37,943	259,791	1.0%	99

** % of all deliveries. Source: Cost per delivery is based on information contained in WHO guide-lines, CHOICE data base and UNICEF supply catalogue Beneficiary deliveries are estimated by the authors. Applicability rates are estimates based on WHO guidelines (WHO, 2017; WHO, 2015).*

time horizon.

Total annual recurrent cost for the five interventions of the targeted BEmONC package is MWK 487 million (Table 5). The five interventions were selected ex-post by first running the entire package and identifying which interventions contributed to the most benefits

Table 5: Annual recurrent cost of interventions for the Targeted BEmONC package

	Cost per delivery		Beneficiary deliveries	Applicability rate *	Total cost, MKW million
	US$	MWK	Year 2021		Year 2021
1. Clean birth practices	1.05	780	320,591	100.0%	250
2. Neonatal resuscitation	3.57	2,658	153,495	5.0%	20
6. Hygienic cord care	0.41	308	298,342	100.0%	92
8. Kangaroo Mother Care (KMC) for premature babies	1.03	764	157,278	18.1%	22
14. Assisted vaginal delivery	15.18	11,308	182,511	5.0%	103

** % of all deliveries. Source: Cost per delivery is based on information contained in WHO guidelines, CHOICE data base and UNICEF supply catalogue Beneficiary deliveries are estimated by the authors. Applicability rates are estimates based on WHO guidelines (WHO, 2017; WHO, 2015).*

- a feature of the LiST software. These five interventions address the main drivers of neonatal mortality (infection, prematurity and birth trauma) so it is unsurprising that they are featured prominently in this targeted package. Each one is also assessed individually.

In addition to annual recurrent cost, some facilities require some capital expenditure (CAPEX) and periodic repeat of this expenditure. This is for a continuous electricity supply and some equipment. BEmONC training of personnel is also needed in order to complete the interventions.

4.2.2 Electricity supply:

TTwo-thirds of health facilities in Malawi had a regular electricity supply in 2013-14 according to the Malawi SPA report (Table 6).

Table 6: Health facilities with regular electricity supply, 2013-14

	Hospitals	Health Centers	Clinics	TOTAL
Facilities offering normal delivery services	95	414	19	528
Facilities with regular electricity supply	79%	65%	49%	67%
Intervention target rate	90%	90%	90%	90%
Facilities needing regular electricity supply	10	104	8	122

Source: Malawi SPA 2013-14 report

Regular electricity supply is defined in the SPA as: a) facility is connected to a central power grid and has not had an interruption in power supply lasting for more than two hours at a time during normal working hours in the seven days before the assessment; or b) facility has a functioning generator with fuel available on the day of the assessment, or else facility has back-up solar power. This means that 122 facilities needed regular electricity supply in order to meet the 90% target set in this analysis.

A survey of 44 health facilities throughout Malawi in 2017 provides a somewhat different perspective, indicating a higher need for investment in a stable electricity supply. The survey found that all hospitals, nearly all health centers, and about half of health posts had grid connection as their primary energy source (Reuland et al, 2020). If these rates are reasonably representative of the three facility types offering normal delivery services in Table 6, then 92% of facilities offering normal delivery services were connected to the grid.[2]

Over half of the facilities reported they had experienced primary energy source interruptions in the week prior to the survey and that the interruptions lasted 9.1 hours on average. All facilities had experienced interruptions in the last 6 months. Thus, all facilities are in need of a back-up power supply to provide electricity for at least essential services during grid disruptions. However, only somewhat over 60% of the facilities had a back-up power supply. These back-up systems were mostly fuel-based generators but there were also some Photovoltaic (PV) solar systems. About 40% of them were non-functional at the time of the survey, meaning the equipment did not function and/or there was no fuel. Thus, in total, only 38% of facilities with grid connection had a functional back-up power supply (Reuland et al, 2020). This means that 255 facilities in Malawi were in need of a functional back-up power supply in order to meet the 90% target set in this analysis.

[2] The remaining facilities had PV solar systems, wood/coal/gas based systems, and/or fuel-based generators as primary energy sources. Only one surveyed health post did not have a primary energy source.

We assume that a health center on average needs 5 kW of effective electricity supply. Hospitals will generally need more while clinics may need less. We compare the cost of PV solar with battery energy storage system (BESS) and diesel generators capable of supplying the facilities' energy requirement for grid interruptions of up to 12 hours. We estimate the that present value of cost per facility over

Table 7: *Cost of back-up power supply for grid connected health facilities*

	Full BEmONC	Targeted BEmONC	Individual interventions*
Number of facilities	255	255	255
Cost per facility. MWK million	8.68	4.34	2.17
Total cost, MWK million	**2,214**	**1,107**	**553**

Source: Estimates by the authors

Note: *Present value of cost over 15 years at a discount rate of 8%. * Zero cost of KMC.*

15 years is MWK 8.7 million for diesel generators and MWK 21.0 million for PV solar with BESS (see Annex). The high cost of solar is largely because of the BESS capacity needed to supply electricity during a 12-hour grid interruption at night when there is no solar electricity production. We select the lowest cost option. This results in a PV of total cost of MWK 2,214 million over 15 years for the 255 facilities, and is the cost associated with facilities being able to adequately provide all the services of the full BEmONC package during grid interruptions. We assume that the electricity needed for the targeted BEmONC is half of this cost, and half of this for individual interventions (Table 7).

The estimated cost of back-up systems is based on the average electricity requirement of a health center. The cost is therefore somewhat understated because hospitals require larger systems. However, some of the facilities without a functional back-up system may simply need a repair of existing generator, or simply a continuous fuel supply for existing generator. Thus, our cost estimate is overstated for these facilities.

In 2017, a project brought PV solar installations to 85 health facilities in Malawi to cope with grid disruptions. The systems ranged from 5 kW for 64 smaller facilities, 10 kW for 15 medium-sized facilities and 50 kW and 100 kW for six larger district and central hospitals. The project also included 46 solar water heating systems. The CAPEX averaged about US$ 43,000 per health facility and approximately US$ 25,000 for the facilities with 5 kW and 10 kW systems.[3] This cost is lower than the CAPEX of US$ 36,900 that we estimate for a 10 kW system with BESS (see Annex). The cost difference is likely in large part to be associated with the BESS.

4.2.3 Equipment:

The only BEmONC equipment in short supply at the health facilities is dry heat sterilizers or autoclaves for the clean birth practices intervention. A total of 250 units are required to reach the target of availability at 90% of facilities. Unit cost is nearly US$4,000 or MWK 2.95 million, with a total CAPEX of MWK 738 million for both the full and targeted BEmONC package (see Annex). We assume that the CAPEX needs to be repeated after 8 years.

4.2.4 Personnel training:

Training of facilities personnel can greatly enhance the effectiveness of the BEmONC. The Malawi SPA reports that 11% of delivery and newborn care personnel have received training in Integrated Management of Pregnancy and Childbirth (IMPAC) during the past two

Table 8: *Status of personnel training*

	Hospitals	Health Centers	Clinics
Personnel training:			
*IMPAC**	12%	9%	8%
Emergency Obstetrics	19%	16%	17%
Neonatal Resuscitation	34%	33%	32%

** IMPAC: Integrated Management of Pregnancy and Childbirth. Source: Malawi SPA data.*

[3] http://www.itnewsafrica.com/2017/11/solar-project-brings-relief-to-malawi-health-facilities/

years, while 17% received training in emergency obstetrics and 33% in neonatal resuscitation (Table 8). This means that practically all delivery and newborn care personnel could benefit from BEmONC training and we calculate the cost of training for all such personnel.

Cost of training is US$944 or MKW 703,000 per person, with a total cost of MWK 2,728 million for the full BEmONC package, MWK 903 million for the targeted BEmONC package and in the range of MWK 283-748 million for individual interventions. Training of all delivery and newborn care personnel is repeated every two years to sustain the effectiveness of the BEmONC intervention. The cost of training per person is for a facility- based mentorship-style intensive BEmONC training set up taken from Ghana (see Annex).

4.2.5 Supply Chain Management:

Along with well-trained personnel, continuous electricity supply and well-functioning medical equipment, having an adequate availability of BEmONC related supplies and medicines at all health facilities at all times is essential for provision of services and reduction in neonatal mortality. This involves timely procurement, predictable delivery times and customs clearance, efficient distribution

Table 9: Total cost of interventions 2020-2035, MWK million

	Electricity	Equipment	Personnel training	Inventory	Recurrent	Total cost
Full BEmONC package	2,211	1,136	13,543	174	11,580	28,644
Targeted BEmONC package	1,106	1,136	4,483	69	5,018	11,812
KMC for premature babies	0	0	1,592	2	224	1,818
Hygienic cord care	553	0	1,405	17	947	2,921
Clean birth practices	553	1,136	1,515	37	2,574	5,815
Neonatal resuscitation	553	0	1,674	4	210	2,441
Assisted vaginal delivery	553	0	3,714	9	1,063	5,339

Note:Present value (PV) of costs discounted at 8%. Source: Estimates by the authors.

to health facilities, and a well-functioning inventory management system. Making improvements on all these dimensions takes time and is more appropriately considered in the context of the entire health system, not just for BEmONC. Thus, a first step to ensure adequate availability of supplies and medicines is to increase inventory. We have incorporated a cost of increase in inventory equal to 30% of annual consumption of supplies and medicines. As this is a one-time cost it has minimal effect on total cost and BCRs.

Table 10: Shares of total cost of interventions 2020-2035

	Electricity	Equipment	Personnel training	Inventory	Recurrent
Full BEmONC package	8%	4%	47%	1%	40%
Targeted BEmONC package	9%	10%	38%	1%	42%
KMC for premature babies	0%	0%	88%	0%	12%
Hygienic cord care	19%	0%	48%	1%	32%
Clean birth practices	10%	20%	26%	1%	44%
Neonatal resuscitation	23%	0%	69%	0%	9%
Assisted vaginal delivery	10%	0%	70%	0%	20%

Source: Estimates by the authors.

4.2.6 Total cost:

Total cost of the full BEmONC package over a period from 2020 to 2035 is MWK 28,644 million (Table 9). Cost of the targeted package is somewhat less than half the cost, of which the cost of clean birth practices and assisted vaginal delivery are the most expensive. Personnel training represents the largest cost component for the full package while recurrent cost is the largest component for the targeted package (Table 10).

4.3 Benefits

Table 11: Efficacy of interventions in the LiST model

	Efficacy	Health outcome
1. Clean birth practices	0.27	% of neonatal mortality due to Sepsis
	0.38	% of neonatal mortality due to Tetanus
	0.6	% of maternal mortality due to Sepsis
2. Neonatal resuscitation	0.1	% of neonatal mortality due to Prematurity
	0.3	% of neonatal mortality due to Asphyxia
3. Antibiotics for PRoM	0.39	% of neonatal mortality due to Sepsis
	0.12	% of neonatal mortality due to Prematurity
	0.8	% of maternal mortality due to Sepsis
4. Active management of third stage labor	0.775	% of maternal mortality due to Postpartum hemorrhage
5. Induction of labor lasting 41+ weeks	NA	
6. Hygienic cord care	0.4	% of neonatal mortality due to Tetanus
	0.4	% of neonatal mortality due to Sepsis
7. Thermal care for premature babies	NA	
8. Kangaroo Mother Care (KMC) for premature babies	0.51	% of neonatal mortality due to Prematurity
9. Case management of neonatal sepsis with antibiotics	NA	
10. Manual removal of placenta	0.3	% of maternal mortality due to Postpartum hemorrhage
11. Immediate drying and newborn stimulation	NA	
12. Parenteral admin of anticonvulsants	0.6	% of maternal mortality due to Hypertensive disorders
13. Parenteral admin of antibiotics	0.39	% of neonatal mortality due to Sepsis
	0.12	% of neonatal mortality due to Prematurity
	0.8	% of maternal mortality due to Sepsis
14. Assisted vaginal delivery	0.77	% of stillbirths that are intrapartum
	0.4	% of neonatal mortality due to Asphyxia
	0.388	% of maternal mortality due to Other direct causes
15.Removal of retained products of conception	0.3	% of maternal mortality due to Postpartum hemorrhage

Source: https://listvisualizer.org/

NA=not applicable as these interventions are already provided at 90% or more of the health facilities with normal delivery services.

The main benefit of BEmONC is reduced neonatal mortality. Some of the interventions also reduce maternal mortality and still births. The Lives Saved Tool (LiST) was used to estimate these benefits. The LiST model estimates these benefits based on:

1. the difference between intervention target rates (here 90%) and the baseline coverage rates in Table 2; and
2. the efficacy of each intervention in the BEmONC package.

The efficacy is the percentage reduction in a health outcome from implementing an intervention. For the BEmONC interventions the efficacies in LiST range from 10% to 80% (Table 11). The interventions reduce neonatal mortality by reduction in mortality from sepsis, tetanus, prematurity, and asphyxia. The only intervention reducing stillbirths is assisted vaginal delivery. Maternal mortality is reduced

Table 12: Estimated averted deaths and stillbirths 2021-2035

	Neonatal	Maternal	Stillbirths	Total
Full BEmONC package	40,177	8,259	33,602	82,038
Targeted BEmONC package	37,215	2,019	33,602	72,836
Assisted vaginal delivery	10,144	467	33,602	44,213
KMC for premature babies	8,556	0	0	8,556
Hygienic cord care	9,748	0	0	9,748
Clean birth practices	6,690	1,554	0	8,244
Neonatal resuscitation	8,118	0	0	8,118

Source: Estimates by LiST.

by reduction in mortality from maternal sepsis, postpartum hemorrhage, hypertensive disorders, and "other direct causes."

The LiST output is the percentage reduction in neonatal mortality, maternal mortality and stillbirths, which are applied to the baseline annual cases of these health outcomes to arrive at an estimate of annual deaths and stillbirths averted by the intervention from 2021 to

Table 13: Benefits of interventions 2020-2035, MWK million

Full BEmONC package	442,456
Targeted BEmONC package	370,905
Assisted vaginal delivery	101,768
KMC for premature babies	81,661
Hygienic cord care	93,038
Clean birth practices	74,632
Neonatal resuscitation	77,481

Source: Estimates by the authors

Note: Present value (PV) of benefits discounted at 8%.

2035.

Implementation of the full BEmONC package is estimated to avert nearly 50,000 neonatal and maternal deaths and over 33,000 stillbirths from 2021 to 2035 (Table 12). The targeted package achieves 90% of the neonatal deaths averted by full package, and one-quarter of the maternal deaths and 100% of the stillbirths. Each of the five interventions of the targeted package achieves fairly similar results in terms of averting neonatal deaths while only two of them result in maternal death reduction and only one in averting stillbirths. In percentage terms, the full BEmONC package reduces neonatal mortality by 15%, maternal mortality by 19% and stillbirths by 13%.

Table 14: Cost and benefits of interventions

	Cost	Benefit	BCR
Full BEmONC package	28,644	442,456	15
Targeted BEmONC package	11,812	370,905	31
Assisted vaginal delivery	5,339	101,768	19
KMC for premature babies	1,818	81,661	45
Hygienic cord care	2,921	93,038	32
Clean birth practices	5,815	74,632	13
Neonatal resuscitation	2,441	77,481	32

Note: Discount rate is 8%.

The full BEmONC package provides over MWK 600 billion in benefits from 2021 to 2035 and the targeted package achieves 84% of these benefits (Table 13). Of each individual intervention in the targeted package, implementation of assisted vaginal delivery provides by far the largest benefit due to stillbirths averted.

4.4. Benefit-Cost Analysis

Table 15: Sensitivity of BCRs to changes in assumptions (BEmONC Interventions)

Intervention	Base case	30% less neonatal deaths averted	30% less maternal deaths averted	Stillbirths averted: Valuation at 50% of neonatal deaths averted	50% increase in recurrent cost (supplies, medicines, personnel)	50% increase in personnel training cost	100% increase in electricity cost
Full BEmONC	15.4	11.4	14.8	21.0	12.8	12.5	14.3
Targeted BEmONC	31.4	22.4	31.0	44.8	25.9	26.4	28.7
Assisted vaginal delivery	19.1	13.6	18.9	48.8	17.3	14.1	17.3
KMC for premature babies	44.9	31.4	44.9	44.9	42.3	31.2	44.9
Hygienic cord care	31.9	22.3	31.9	31.9	27.4	25.7	26.8
Clean birth practices	12.8	9.5	12.3	12.8	10.5	11.4	11.7
Neonatal resuscitation	31.7	22.2	31.7	31.7	30.4	23.6	25.9

The benefits of the full BEmONC package are 15 times larger than the costs of implementation. The ratio increases to 31 for the targeted package (Table 14). The individual intervention with the largest BCR is Kangaroo Mother Care (KMC) for premature babies. This is mostly driven by our assumption that KMC does not require electricity generation to be implemented effectively. Clean birth practices have the lowest BCR. BCRs using discount rates of 5% and 14% are presented in the Annex. BCRs are not very much different than for the base case discount rate of 8% used in Table 13.

4.5 Sensitivity Analysis

An analysis of the sensitivity of the BCRs to changes in benefits and major cost components are presented in Table 15. The base case is BCRs based on 8% discount rate. The BCRs stay above 9 for a 30% decline in each of major benefits and for a 50% or more increase in each of major cost components. And the BCRs increase substantially for an alternative valuation of averted stillbirths.

Specifically, if averted neonatal deaths are 30% less than estimated, the BCRs decline by about the same percentage because averted neonatal deaths constitute 86-97% of total benefits depending on the specific BEmONC intervention. The BCRs are very insensitive to changes in averted maternal deaths given that this benefit is a very small share of total benefits. On the other hand, the BCRs are sensitive to the valuation of averted still births. In the base case, averted stillbirths are valued very conservatively at cost of pregnancy and delivery. If, however, each averted stillbirth is valued at 50% of an averted neonatal death, then the BCRs increase by 35-43% for the full and targeted BEmONC packages and more than double for the assisted vaginal delivery intervention.

A 50% increase in annual recurrent cost of supplies, medicines and personnel reduces the BCRs by 4-18% depending on the intervention. A 50% increase in personnel training cost reduces the BCRs by 12-30%, and a 100% increase in the cost of providing continuous electricity supply reduces the BCRs up to 18%.

5. Nutrition supplements in pregnancy

As discussed above, Malawi has the highest rate of preterm birth in the world. Being born prematurely is associated with a 6.8 times higher risk of mortality in the first 30 days, and a 2.5 times higher mortality risk in the post-neonatal period compared to normal gestation (Katz et al., 2013). Therefore, significant reductions in neonatal and infant mortality could be achieved if the prevalence of prematurity were reduced. Prematurity in Malawi appears to be driven by a number of factors associated with disease exposure, nutrition and maternal characteristics. A study of 2,149 pregnant women in Southern Malawi noted that being repeatedly exposed to malaria increased the odds of late preterm birth by 1.99 (1.05-3.79). Being anaemic or under the age 20 increased the odds of early preterm birth by 1.73 (1.03 – 2.90) and 1.95 (1.08 – 3.52) respectively (Broek, Jean-Baptiste and Neilson, 2014).

Nutrition supplements, such as multiple micronutrients and calcium, taken during pregnancy have been shown to reduce the risk of prematurity. Smith et al., (2017) analyze 17 randomized control trials involving 112,953 women and note an 8% reduction in prematurity when taking multiple micronutrients (MMN). They also show, among other results, that maternal weight as measured by body-mass index (BMI) is the most important modifier for this effect with underweight mothers reducing their risk of having a premature birth by 16% compared to 6% for non-underweight mothers. Calcium supplementation has also been shown to reduce prematurity risk with a relative risk of 0.88 across 10 randomized controlled trials (Imdad, Jabeen and Bhutta, 2011).

Currently, Malawi provides women with free iron and folic acid (IFA) tablets during antenatal care visits (ANC). The program appears to work well, with 97% of ANC facilities offering iron tablets, 94% offering folic acid tablets and 92% offering combined iron and folic acid tablets (Ministry of Health [Malawi] and ICF, 2014). In the most recent Demographic and Health Survey, nine out of ten women reported taking iron tablets during their last pregnancy. However, only just over 50% reported taking iron tablets for more than 60 days of their pregnancy (National Statistical Office [Malawi] and ICF, 2017).

In this section we conduct a cost-benefit analysis of three interventions:

1. Replace IFA supplements with MMN supplements
2. Introduce calcium supplementation in addition to the standard course of IFA
3. Replace IFA supplements with MMN and calcium supplementation

The interventions would leverage the existing infrastructure that is able to procure and deliver IFA to approximately 95% of health facilities throughout the country.

The time period of analysis is 11 years from 2020 to 2030 inclusive. It is assumed that planning, procurement and transitioning occurs in the first year (2020) with the new supplements first delivered in 2021. We assume that all women who make ANC visits, estimated at 98% (National Statistical Office Malawi and ICF, 2017) would receive these tablets, or a prescription, for the duration of their pregnancy, starting with the first ANC visit. DemProject, a population projection tool that is part of the suite of Spectrum applications, provides the number of expected births for each year. In 2021 this is 651,331 rising to 865,918 by 2030. We add 10% to each birth projection to estimate total pregnancies, which is the primary cost driver for the interventions.

Pregnant women in Malawi tend to make their first ANC visit late, with only 24% making their first ANC visit in months 1-3, another 51% making their first visit in months 4-5, and 23% of women making their first visit in months 6-9 (National Statistical Office Malawi and ICF, 2017). These figures are used to estimate the number of tablets provided across each intervention on the assumption the ANC provider estimates correctly, on average, the remaining number of months left in the pregnancy. Each pregnant woman is advised to take one MMN tablet and / or four 600mg calcium carbonate tablets per day, equivalent to almost 1g of elemental calcium. In 2021, more than 700,000 pregnant women are assumed to take the new supplements - 97 million MMN tablets and / or 389 calcium carbonate tablets (see Table 16). These figures rise in subsequent years commensurate with the expected growth in the number of pregnancies per year.

5.1. Costs

There are two broad categories of costs considered by the analysis – the costs of the tablets themselves, and programmatic expenses associated with ramping up the interventions including planning, behavior change communication (BCC) and training. Since the intervention leverages existing tablet distribution infrastructure and targets those women who already go to ANC, there are no additional distribution or beneficiary costs.

Table 16: Total pregnancies, women-months, tablets and marginal costs of the tablets associ-ated with the interventions in 2021

	Number of pregnancies	Women-months of pregnancy covered by interventions	Number of MMN tablets required, millions	Number of 600mg calcium carbonate tablets required, millions	Total marginal cost of MMN tablets (MWK, millions)	Total marginal cost of calcium tablets (MWK, millions)
First ANC visit made in months 1-3	171,951	1,203,660	36	144	184	2,980
First ANC visit made in months 4-5	366,830	1,650,733	50	198	252	4,086
First ANC visit made in months 6-7	153,323	383,308	11	46	58	949
First ANC visit made in months 8+	10,747	5,373	0	1	1	13
TOTAL	**702,851**	**3,243,075**	**97**	**389**	**495**	**8,028**

Unit costs of the two supplements are sourced from the UNICEF supply catalogue (UNICEF, 2020), with the catalogue price increased by 30% to account for 15% shipping and 15% wastage. Because MMN tablets contain IFA and are designed to replace IFA tablets, the cost of IFA is subtracted from the MMN costs to determine the marginal cost of investment. The final unit cost figures applied are MWK 5 per MMN tablet and MWK 21 per 600mg calcium carbonate tablet. As reported in Table 15, the marginal costs of MMN are MKW 495 million, while for calcium it is MWK 8,028 million in 2021.

Programmatic ramp up costs per woman targeted are assumed to be MWK 1079 for planning and coordination, MWK 1499 for BCC and MWK 1079 for training, following a study which estimates the costs of scaling up breastfeeding promotion (Holla-Bahr et al., 2015). We further assume that planning and coordination costs are incurred once in 2020, while training and BCC start in the same year and taper off to zero by 2025. Note that these costs are in addition to existing program costs associated with IFA distribution in Malawi with the implicit assumption that after five years, the use of these supplements will be normalized in a way that does not require any extra coordination, training and BCC. Lastly, we assume that each intervention requires the same program costs.

The total costs of the interventions to 2030 are presented in Table 17. The MMN only intervention is by far the least costly of the three, requiring only MWK 10,979 million (undiscounted) over 11 years. This compares to MWK 98,766 million (undiscounted) and MWK 104,531 million (undiscounted) for calcium only, and both MMN and calcium respectively.

Table 17: Coverage, cost and outcomes over the period of analysis, 2020-2030

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
COVERAGE											
Number of pregnancies covered by intervention	-	702,851	727,950	753,714	779,920	806,301	832,595	858,622	884,308	909,609	934,412
COST COMPONENTS, MWK millions											
(A) Program Costs	2,157	1,180	917	633	327	-	-	-	-	-	-
(B) MMN tablet costs (above IFA)	-	495	512	530	549	568	586	604	622	640	658
(C) Calcium tablet costs	-	8,028	8,315	8,609	8,908	9,210	9,510	9,807	10,101	10,390	10,673
INTERVENTION COSTS, MWK millions											
Intervention 1, MMN only (A+B)	2,157	1,675	1,429	1,163	876	568	586	604	622	640	658
Intervention 2, Calcium only (A+C)	2,157	9,208	9,232	9,242	9,236	9,210	9,510	9,807	10,101	10,390	10,673
Intervention 3, MMN and Calcium (A+B+C)	2,157	9,703	9,744	9,772	9,785	9,777	10,096	10,412	10,723	11,030	11,331
NEONATAL DEATHS AVERTED											
Intervention 1, MMN only	-	429	445	461	477	493	509	525	541	556	571
Intervention 2, Calcium only	-	502	520	538	557	576	594	614	632	650	667
Intervention 3, MMN and Calcium	-	907	939	972	1,006	1,041	1,074	1,108	1,141	1,173	1,205
MATERNAL DEATHS AVERTED											
Intervention 1, MMN only	-	-	-	-	-	-	-	-	-	-	-
Intervention 2, Calcium only	-	50	52	54	56	58	60	62	64	65	67
Intervention 3, MMN and Calcium	-	50	52	54	56	58	60	62	64	65	67
STILLBIRTHS AVERTED											
Intervention 1, MMN only	-	895	927	960	993	1,027	1,061	1,093	1,126	1,159	1,190
Intervention 2, Calcium only	-	-	-	-	-	-	-	-	-	-	-
Intervention 3, MMN and Calcium	-	895	927	960	993	1,027	1,061	1,093	1,126	1,159	1,190
PRETERM BIRTH AVERTED											
Intervention 1, MMN only	-	5,940	6,152	6,370	6,591	6,814	7,037	7,257	7,474	7,688	7,897
Intervention 2, Calcium only	-	7,054	7,306	7,564	7,827	8,092	8,356	8,617	8,875	9,129	9,378
Intervention 3, MMN and Calcium	-	12,590	13,040	13,501	13,971	14,443	14,914	15,381	15,841	16,294	16,738

LOW BIRTHWEIGHT AVERTED											
Intervention 1, MMN only	-	4,064	4,209	4,358	4,510	4,663	4,815	4,965	5,114	5,260	5,403
Intervention 2, Calcium only	-	3,765	3,899	4,037	4,177	4,319	4,460	4,599	4,737	4,872	5,005
Intervention 3, MMN and Calcium	-	7,634	7,906	8,186	8,471	8,757	9,043	9,325	9,604	9,879	10,149
CASES OF STUNTING AVERTED											
Intervention 1, MMN only	-	2,092	3,407	4,509	5,682	6,956	7,193	7,430	7,668	7,904	8,135
Intervention 2, Calcium only	-	1,944	3,128	4,111	5,159	6,301	6,515	6,730	6,945	7,158	7,368
Intervention 3, MMN and Calcium	-	3,940	6,380	8,417	10,586	12,949	13,389	13,831	14,274	14,712	15,143
INTERVENTION BENEFITS, MWK millions											
Intervention 1, MMN only	-	9,297	12,034	13,755	16,397	19,407	21,060	22,833	24,734	26,750	28,899
Intervention 2, Calcium only	-	10,200	12,770	14,424	16,994	19,914	21,629	23,504	25,484	27,591	29,840
Intervention 3, MMN and Calcium	-	19,020	24,187	27,481	32,567	38,372	41,657	45,200	48,985	53,003	57,309

5.2 Benefits

The provision of MMN and / or calcium leads to improvements in mortality risk and birth outcomes, which we estimate using the Lives Saved Tool (LiST).

Baseline coverage is set to 70% for IFA, 0% MMN and 0% calcium supplementation. While 90% of women state that they take iron tablets during pregnancy, many do not attend their first ANC visit until much later in the pregnancy and therefore, as noted above, only 50% take IFA tablets for more than 60 days (National Statistical Office Malawi and ICF, 2017). Nevertheless, a study from Malawi demonstrates benefits from even 45 days consumption of IFA (Chikakuda et al. 2018). Therefore, we set the effective baseline coverage at 70%, halfway between the 50% figure for 60 days consumption and 90% figure for any consumption of iron. In the intervention scenarios, coverage is set to 70% for MMN and 70% for calcium on the assumption that consumption of these supplements will follow a similar pattern as for IFA. In the interventions with MMN, IFA is completely replaced and the coverage is set to 0%. In the calcium only intervention, IFA coverage is assumed to continue at 70%.

The consumption of MMN and CA generates a number of benefits relative to consumption of IFA. One pathway of benefit is via the reduction in preterm births and low birth-weight births. In LiST, the effect on preterm from MMN is modeled as a 16% reduction for mothers with BMI less than 18.5 and 6% reduction for those with BMI more than 18.5 (Smith et al., 2017). MMN reduces low birth weight by 3% but only for women with BMI more than 18.5 following Smith et al. (2017). Having a slightly higher percentage of babies reach full term also has a moderate effect on low birth weight prevalence. Calcium supplementation reduces prematurity by a uniform 12% but only for those households which are food insecure (Imdad et al. 2011). As with MMN, improving prematurity outcomes also reduces the prevalence of low birth weight.

In the Malawian context, where 11% of women of reproductive age are underweight, the interventions scaled up to 70% coverage are expected to reduce preterm births by 5% for MMN supplementation, 6% for calcium supplementation and 10.7% for MMN and calcium supplementation together.[4] The interventions also reduce low birth weight by 4%, 3% and 7% respectively. In absolute terms, these improvements represent several thousand cases of avoided poor birth outcomes (see Table 17).

Improvements in birth outcomes reduce the risk of neonatal mortality substantially (Katz et al., 2013) and childhood stunting (LiST, 2016). Overall, the interventions scaled up to 70% coverage reduce neonatal deaths by 2.9% for MMN only, 3.4% for calcium supplementation only and 6.2% for both. The prevalence of childhood stunting is reduced by 0.5%, 0.6% and 1% respectively in steady state.

Evidence shows that MMN also reduces in the incidence of stillbirths by 9% (Haider and Bhutta, 2015), while calcium supplementation reduces maternal deaths from hypertensive disorders by 20% (Ronsmans et al., 2011). A timeline of all the benefits from the interventions is presented in Table 17.

Mortality, stillbirth, low birth weight and stunting outcomes are monetized as per the discussion in Section 3. A breakdown of monetized benefits for 2021 is presented in Table 18. The analysis shows that MMN yields almost MWK 14.5 billion worth of benefits in that year, mostly in avoided neonatal mortality and stillbirths. Calcium supplementation only yields MWK 10.2 billion worth of benefits, mostly in avoided neonatal mortality. The combined intervention has the largest absolute benefit of nearly MWK 24.2 billion. These benefit figures represent underestimates since we do not include avoided morbidity benefits, avoided child mortality associated with reduced stunting and reduced maternal anemia.

Table 18: Monetized benefits of interventions for 2021, MWK millions, 8% discount rate

	MMN only	Calcium only	MMN and Calcium
Neonatal mortality averted	5,045	5,903	10,666
Maternal mortality averted	-	428	428
Stillbirth averted	83	-	83
Low birth weight averted	1,543	1,429	2,897
Stunting averted	2,626	2,440	4,946
Total benefits for 2021, MWK millions	9,297	10,200	19,020

[4] The figures from the individual interventions do not sum to the combined intervention due to a moderate amount of overlap in benefits associated with the combined intervention.

5.3 Summary and Conclusion

Comparing costs to benefits, an intervention that replaces IFA with MMN only has the highest benefit-cost ratio (BCR) of 14 at an 8% discount rate (see Table 19). This outperforms the calcium only intervention, which has a BCR of 1.9, and the combined intervention, which has a BCR of 3.5. The high cost of calcium tablets is a key factor in the differences between these interventions. MMN is significantly cheaper per unit. Furthermore, given current spending on IFA a government or donor looking to fund this intervention would only need to provide the difference in costs between IFA and MMN.

The high BCR of MMN is sensitive to the assumption around value of avoided stillbirth. With avoided stillbirth considered a zero-welfare benefit, the BCR is 14. Conversely, if an avoided stillbirth is valued the same as a neonatal death the BCR jumps to 26.

It should be noted that the World Health Organization (WHO) recently came out in support of MMN supplementation (containing iron and folic acid) in contexts of poor maternal nutrition (WHO, 2020). This updates a previous recommendation where support for MMN was less clear (WHO, 2016). The new recommendations suggest that any MMN tablets provided to the pregnant mothers should contain at least 60 mg of iron, if anemia is widespread. Given the prevalence of anemia in Malawi, particularly among pregnant women, the government should ensure MMN tablets contain this level of iron (many MMN tablets contain only 30mmg of iron) if the intervention is rolled out.

Table 19: Cost, benefits and benefit-cost ratios of nutrition interventions to reduce prema-turity 2020-2030

MMN only			
Discount rate	Cost	Benefit	BCR
5%	9,323	292,620	31.4
8%	8,570	121,829	14.2
14%	7,426	47,029	6.3
Calcium only			
Discount rate	Cost	Benefit	BCR
5%	76,251	284,983	3.7
8%	66,305	126,624	1.9
14%	51,695	54,516	1.1
MMN and calcium			
Discount rate	Cost	Benefit	BCR
5%	80,646	563,696	7.0
8%	70,096	242,365	3.5
14%	54,602	98,988	1.8

5.4 Sensitivity Analysis

We conduct several one-way sensitivity analyses to assess how results change as some of the key assumptions change. The results are presented in Table 20 below. The results indicate that for interventions involving MMN only, results are most sensitive to changes in valuation approach for stillbirths. For example, valuing stillbirths avoided as much as neonatal deaths avoided would increase the BCR from 14.2 to 25.6 at an 8% discount rate. For calcium only and MMN and calcium interventions, results are most sensitive to changes in expected benefits by 50%. In all scenarios the broader policy implications holds that scale up of MMN intervention has the greatest return on investment, relative to calcium and MMN + calcium together.

Table 20: Sensitivity of BCRs to changes in assumptions (MMN and Ca Supplementation)

Adjustment	MMN only BCR	Calcium only BCR	MMN and Calcium BCR
Base Case	14.2	1.9	3.5
Increase tablet costs by 25%	11.1	1.6	2.8
Decrease tablet costs by 25%	19.9	2.5	4.6
Increase scale up costs by 50%	11.1	1.8	3.3
Decrease scale up costs by 50%	19.7	2.0	3.6
Increase benefits by 50%	21.3	2.9	5.3
Decrease benefits by 50%	7.1	1.0	1.8
Value stillbirths avoided as much as neonatal deaths avoided	25.6	1.9	4.8
Value avoided stillbirths at 50% of neonatal deaths avoided	19.9	1.6	4.1

Note: All BCRs are reported at 8% discount rate

6. Summary and Discussion of Results

Despite severe wealth and resource constraints, Malawi achieved a two-thirds reduction in overall child (under 5) mortality between 1990 and 2015, and is one of the few low-income countries to meet the Millennium Development Goal (MDG) in this area (Kanyuka et al, 2015). Progress has continued since then, with a further reduction from 63 deaths per 1,000 live births in 2015 to 50 per 1,000 in 2018 (UNICEF, 2019).

However, this overall success masks the fact that the decline in neonatal mortality has been slower, despite the proportion of births in medical facilities increasing (MDHS, 2017). Newborn mortality in 2018 stood at 22 per 1,000 births (UNICEF, 20019; down from 50 per 1,000 in 1990). Neonatal disorders are the second highest source of disability adjusted life years (DALYs) after HIV/AIDS. Malawi also has one of the highest maternal mortality rates in the world. Taken together addressing maternal and neonatal health is a high priority.

Intrapartum related events are the leading cause of neonatal mortality in Malawi (39%), followed by preterm birth complications (28%), and sepsis (16%) (WHO, 2018). The neonatal mortality risk is compounded by the rate of preterm birth at 18%, which is the highest in the world (Katz et al., 2013). Hemorrhages, eclampsia, obstructed labor and abortions are the most common direct causes of maternal deaths, with sepsis, hemorrhage, eclampsia and obstruction In Malawi's rural facilities, sepsis, hemorrhage, eclampsia and obstruction accounting for 95% of obstetric complications, while other direct/indirect causes account for the remaining 5% (van den Akker et al, 2011).

Although the underlying causes of neonatal and maternal mortality are complex and interdependent, two opportunities present a pathway to help improve the situation. These are the provision of good quality of care in health facilities offering delivery services and the improvement of the nutritional status of pregnant women.

In this report we have assessed the costs and benefits of delivering improved emergency obstetric and newborn care (EmONC) and nutritional supplements, specifically in the following ways:

1. A full package of 15 different Basic emergency obstetric and newborn care (BEmONC) interventions scaled up to 90% of health facilities, including adequate back up electricity
2. A targeted package of 5 BEmONC interventions addressing the largest causes of neonatal mortality scaled up to 90% of health facilities, including adequate back up electricity
3. Individual neonatal mortality interventions scaled up to 90% of health facilities:
    a. Clean birth practices
    b. Kangaroo mother care
    c. Hygienic cord care
    d. Assisted vaginal delivery
    e. Neonatal resuscitation
4. Replacing iron and folic acid (IFA) with multiple micronutrient supplements (MMN) delivered during antenatal care (ANC) visits
5. Providing calcium supplements during ANC visits
6. Providing MMN and calcium supplements during ANC visits

Our analysis shows that many of these interventions have benefit-cost ratios (BCRs) of greater than 15 and could be very good uses of resources to improve maternal and neonatal health in Malawi.

Of the interventions focusing on improving care in medical facilities, the targeted package (option 2) has a very high BCR of 31 at 8% discount rate. Offering these interventions separately (option 3) would have a lower impact (and similar or lower BCRs), because of the economies of scale in health training and electricity provision associated with the package. The exception to this is Kangaroo Mother Care alone. The full package of 15 interventions (option 1) has a very favorable BCR of 15, but this is driven mostly by the five interventions in option 2, which deliver about 85% of the total benefits.

For the nutritional interventions, replacing iron and folic acid supplements by multiple micronutrients (option 4) has the highest BCR (14), but the options involving calcium supplements have substantially lower BCRs because of the higher cost of the calcium tablets.

These results suggest that policy makers should ensure that there are sufficient trained health workers in medical facilities to deliver the package of five interventions to improve the outcomes of births for both mother and baby. Given current staffing constraints, this represents the biggest challenge and cost. Additionally, a secure electricity supply, medical disinfectants and some items of basic equipment need to be provided to deliver the care package. The upfront cost of the targeted BeMONC package is MWK 11,812 million with training representing just over half the cost. In 2021-2022, the cost is around MWK 2,125 every two years rising to MWK 2,574 million every two years by 2034-2035. The recurrent costs are predominantly staff time and bi-annual training. The intervention would avoid around 2,000 neonatal deaths, 110 maternal deaths and 1,800 intra-partum still births in 2021, with these figures rising in line with expected increase in deliveries over time.

The second priority should be to replace the current IFA supplements given to pregnant women during antenatal visits by MMN supplements. The MMN intervention would require around MWK 600 million per year in additional investment beyond what is already been paid for IFA tablets. It would also require upfront investment of MWK 2,157 in planning, coordination and behavioral change. Over five years we expect these costs to reduce to zero (relative to counterfactual) as MMN becomes normalized as part of providing routine ANC. The MMN intervention would avoid around 430 neonatal deaths and 900 stillbirths in 2021, rising over time to reflect increase in expected births. Since 90% of pregnant women are already receiving IFA via antenatal care visits, there should be no significant constraints to scale up.

7. Limitations

This paper recognizes the larger scope of the systemic challenges limiting the delivery of quality maternal and neonatal health services in Malawi. There is an acute shortage of health personnel including doctors and Health Surveillance Assistants, with the sector also suffering from limited in-service training and poor staff retention. The quality of health care is also compromised by drug stockouts with the health care system often experiencing scarcity of essential medical products and technologies. Some of the factors behind this include inadequate funding, irrational use of medicines, leakage and pilferage. Supply chain management is poor with weak supply chains, inadequate basic equipment and infrastructure as well as electricity problems for the cold chain.

The existence of parallel reporting systems has also created structural challenges and weakened the mainstream monitoring and evaluation system. Health care financing in Malawi also remains a challenge. In order to make a systemic difference, all these issues would need to be looked at and addressed which is beyond the scope of this paper.

Table 21: *Summary BCR Table of Interventions Addressing Maternal and Neonatal Mortality*

Intervention	Cost	Benefit	BCR
Full BEmONC package	28,644	442,456	15
Targeted BEmONC package	11,812	370,905	31
Assisted vaginal delivery	5,339	101,768	19
KMC for premature babies	1,818	81,661	45
Hygienic cord care	2,921	93,038	32
Clean birth practices	5,815	74,632	13
Neonatal resuscitation	2,441	77,481	32
MMN only	8,570	121,829	14
Calcium only	66,305	126,624	1.9
MMN and calcium	70,096	242,365	3.5

Note: All costs and benefits assume 8% discount rate

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9. Appendices

9.1 Valuation of mortality risk reduction

We value each death avoided using a value of statistical life year (VSL) of $9.4m USD (2015 dollars) – representing approximately 160 times income as measured by income per capita PPP - transferred to Malawi using an income elasticity of 1.5.

To estimate these values, we take the GDP per capita figure in 2018 Int$ for both Malawi and the USA, and estimate the VSL, in time **t**=0, 2018.

$$VSL_t = \left(\frac{GDP\ pc_{Malawit}}{GDP\ pc_{USAt}}\right)^{0.5} * 160\ * GDP\ pc_{Malawit} \qquad \text{(Eq. 1)}$$

Following Cropper et al. (2019) we estimate each subsequent VSL in the time series according to the following formula:

$$VSL_{t+1} = VSL_t * [(1 + g_t)]^e \qquad \text{(Eq. 2)}$$

Where $\mathbf{g_t}$ is the GDP per capita growth rate between period **t** and **t**+1 and **e**=1.5.

Robinson, Hammitt and O'Keeffe (2019) suggest that when the beneficiaries of health interventions are likely to be the very old or the very young, analysts should also include an approach that values each life year lost from an avoided death. This time series of value of statistical life year (VSLY) across years t is calculated by:

$$VSLY_t = \frac{VSL_t}{LE_t(average\ adult\ age_t)} \qquad \text{(Eq. 3)}$$

where the numerator, VSL is given by the equation 1, and the denominator LE (average adult age) is the life expectancy of the average adult age, where adult is defined as anyone aged 15 and above. Age profiles to estimate average age are sourced from Riahi et al. 2017 (SP2 medium term scenario) while the life table for Malawi is sourced from WHO (2019). The benefit of avoided mortality is VSLY* avoided years of life lost from each avoided death.

9.2 Details of interventions

Clean birth practices – A set of procedures to reduce infection during delivery, including use of soap and water or hand sanitizer, gloves, draw sheets and antiseptic.

Neonatal resuscitation – An emergency procedure focused on supporting the approximately 10% of newborn children who do not readily begin breathing, putting them at risk of irreversible organ injury and death.

Kangaroo Mother Care (KMC) for premature babies – Holding of newborn babies with skin-to-skin contact for premature births.

Assisted vaginal delivery – Vaginal delivery assisted by use of forceps or vacuum extractor.

Hygienic cord care - Procedure of cutting the cord with a new or sterilized equipment and use of chlorhexidine.

Active management of third stage labor - Involves giving a prophylactic uterotonic, early cord clamping and controlled cord traction to deliver the placenta. Oxytocin is the most commonly used uterotonic agent and the primary drug of choice.

Induction of labor lasting 41+ weeks - Process of inducing labor and stimulating childbirth after 41 weeks of low-risk pregnancies in order to reduce the risk of infant death.

Thermal care for premature babies – The process of providing warmth to newborn infants using incubators or radiant warmers, or by keeping the baby wrapped in clothes in a warm room, or by some other means. It helps prevent hypothermia and complications associated with it in the newborns.

Case management of neonatal sepsis with antibiotics - The treatment of (suspected) neonatal sepsis by aggressive initiation of antibiotics.

Manual removal of placenta - The evacuation of the placenta from the uterus by hand. It is usually carried out under anesthesia or sedation and analgesia. A hand is inserted through the vagina into the uterine cavity and the placenta is detached from the uterine wall and then removed manually.

Immediate drying and newborn stimulation - Immediate drying prevents newborns from heat loss to the outside environment, stimulates breathing and protects them against infection-related mortality. Newborn stimulation is a therapy to stimulates sense of sight, sound, touch, taste, and smell etc. in them.

Parenteral admin of anticonvulsants - Administration of drugs parenterally for the control of acute seizures.

Parenteral admin of antibiotics - Use of antibiotics for prophylaxis and treatment of maternal sepsis.

Removal of retained products of conception - The removal of any remaining products of conception that are still inside the uterus following a miscarriage, termination of pregnancy or childbirth. This is usually done by manual vacuum aspiration.

Antibiotics for PRoM - Antibiotic therapy for Premature Rupture of Membranes.

9.3 Cost estimation

1. **Back-up electricity supply for grid connected health facilities**

The cost of PV solar with battery energy storage system (BESS) is here compared to the cost of diesel generator as back-up electricity supply for grid connected health facilities. Energy requirement to provide health services at times of grid interruptions is assumed to be 5 kW. This is mostly at health centers. Energy requirement at hospitals is larger.

The PV solar system is designed to meet the electricity requirement of a grid interruption lasting up to 12 hours per incidence with a BESS that has a life of 15 years and 60 kWh storage capacity in case the grid interruption is at night when there is no PV solar electricity production. The PV solar plant has an installed capacity of 10 kW so that it can fully recharge the BESS in one and a half days.

Plant parameters are presented in Table A1. Annual electricity production of the plant is 14,500 kWh based on a solar irradiation that provides an annual yield of 1,450 kWh/kWp of installed capacity. Electricity consumption during grid interruptions is 2,340 kWh per year based on average weekly interruptions of 9 hours, which is the average interruptions reported by health facilities in Malawi (Reuland et al, 2019). Thus the PV solar plant saves the health facility 12,160 kWh of electricity from the grid per year, here valued at US$ 0.1 per kWh.[5] Operations and maintenance (O&M) cost is US$20 per kW.[7]

Total CAPEX of the PV solar system is US$ 36,900 of which two-third is the BESS. Annual cost savings (grid savings less O&M cost) are US$ 1,016 bringing the present value (PV) of cost to US$ 28,204 (MWK 21.0 million) at 8% discount rate (Table A2). The cost is particularly sensitive to the capacity of the BESS. If the BESS only covers an interruption up to 6 hours (50% of base case) then PV of total cost declines to US$ 15,754 or by 45%. The cost is very insensitive to the capacity of the PV plant. If the capacity is 5 kW (instead of 10 kW), PV of total cost only declines to US$ 27,553. This is because of the reduction in grid savings associated with a smaller PV system.

[5] Assumed to be the marginal cost of grid distributed electricity from hydropower plants including transmission and distribution cost and losses.

[6] https://www.renewableenergyworld.com/2020/04/10/solar-battery-energy-storage-vs-diesel-in-east-africa/#gref

Table A1: PV solar back-up electricity supply with battery storage

Energy requirement per health facility	5	kW
Grid interruption (average per week)	9	hours
Grid interruption (max per interruption)	12	hours
Grid interruption (average per week)	45	kWh
BESS storage capacity	**100%**	**% of interruption**
BESS storage capacity	60	kWh
BESS cost	415	US$/kWh
BESS cost	24,900	US$
BESS lifetime	15	years
Solar PV plant	10	kWp
Cost of solar PV plant	1200	US$/kW
Cost of solar PV plant	12,000	US$
Annual yield	1450	kWh/kWp
Plant daily production	40	kWh
Plant annual production	14,500	kWh
Annual production used for interruptions	-2,340	kWh
Annual grid savings	12,160	kWh
Value of grid savings	0.10	US$/kWh
Annual grid savings	1,216	US$
O&M cost	20	US$/kW
Annual O&M cost	200	US$

Table A2: Cost of PV solar system per health facility

Solar PV plant	12,000	US$, CAPEX
BESS	24,900	US$, CAPEX
Grid savings	-1,216	US$ per year
O&M	200	US$ per year
Total lifetime cost, US$	**28,204**	**PV@8%; 15 years**
Total lifetime cost, MWK million	**21.0**	**PV@8%; 15 years**

The parameters for the cost of diesel generator as back-up electricity supply are presented in Table A3. The generator capacity is 5 kW to meet health facility electricity requirement. Fuel consumption at full capacity and cost of generator per kW is from IFC (2019). Fuel cost is assumed to be US$ 1.00 per liter including transportation and distribution cost (net of taxes and duties). O&M cost is assumed to be 10% of generator CAPEX. This brings the present value (PV) of total cost to US$ 11,655 (MWK 8.7 million) at 8% discount rate (Table A4). The PV of total cost is very insensitive to CAPEX of the generator but almost proportional to diesel fuel cost.

Comparing the two back-up systems, the cost of the diesel generator system is less than half of the cost of PV solar system. This is to a large extent due to BESS capacity requirement of the PV solar system to meet electricity requirements when grid interruptions occur at night.

Table A3: Diesel generator back-up electricity supply

Energy requirement per health facility	***5***	***kW***
Grid interruption (average per week)	*9*	*hours*
Grid interruption (max per interruption)	*12*	*hours*
Grid interruption (average per week)	*45*	*kWh*
Generator capacity	*5*	*kW*
Fuel consumption (at full capacity)	*2.4*	*liters/hour*
Fuel consumption per year	*1,123*	*liters*
Fuel cost per liter	*1*	*US$*
Fuel cost per year	*1,123*	*US$*
Cost of generator per kW	*176*	*US$*
Cost of generator	*880*	*US$*
O&M cost per year	*88*	*US$*

Table A4: Diesel generator back-up electricity supply

Generator	880	US$, CAPEX
Fuel cost	1,123	US$ per year
O&M	88	US$ per year
Total lifetime cost, US$	**11,655**	**PV@8%; 15 years**
Total lifetime cost, MWK million	**8.7**	**PV@8%; 15 years**

2. **Equipment cost**

Table A5: Durable equipment cost

	Hospitals	Health Centers	Clinics	TOTAL
Facilities offering normal delivery services	95	414	19	528
Intervention target rate	90%	90%	90%	
Clean birth practices				
Dry heat sterilizer or an autoclave: current coverage	82%	34%	44%	
Facilities needing the equipment	8	234	9	250
Unit cost, MWK million	2.95	2.95	2.95	2.95
Total cost, MWK million	***23***	***689***	***26***	***738***

Source: Physical quantities are derived from the Malawi SPA 2013-14. Unit cost is from UNICEF catalogue (US$3,955 per unit)

3. **Personnel training**

Cost of BEmONC training is US$944 or MKW 703,000 per person. This cost is for a two-week BEmONC training workshop taken from Ghana (Willcox et al, 2017) and adjusted for inflation to 2020. The cost is applied to the staffing pattern per facility as reported in the Malawi SPA 2013-2014, with the target of training 90% of delivery and newborn care personnel. Cost of personnel time for participating in the training is also included as a cost of training.

For the targeted BEmONC package and individual intervention, total training cost is calculated as fixed cost plus a portion of the variable cost that is proportional to the targeted package and single intervention's personnel input requirement to provide the service rendered by the intervention(s). Fixed cost is assumed to be 10% of total cost and includes mainly trainers' travel cost.

Table A6: Full BEmONC package training cost

	Hospitals	Health Centers	Clinics	TOTAL
Number of facilities offering normal delivery services	95	414	19	
Staffing pattern per facility:				
Doctor	1	0	0	
Other Clinician	6	2	2	
Nurse	18	2	1	
Total personnel	2375	1656	57	4088
Training target	90%	90%	90%	
Training need (number of personnel)	2138	1490	51	3679
Cost per person, MWK	703,083	703,083	703,083	
Total direct cost, MWK million	1,503	1,048	36	2,587
Cost of personnel time for training participation				
Number of days per person	10	10	10	
Cost per day, MWK	3,850	3,850	3,850	
Total indirect cost, MWK million	82	57	2	142
Total cost, MWK million				***2,728***
Fixed cost (%)				10%
Fixed cost, MKW million				***273***
Variable cost, MKW million				***2,456***

Source: Staffing pattern is from Malawi SPA 2013-14. Training cost per person is from Willcox et al (2017)

4. Cost and benefits of interventions

Table A7: Cost and benefits of interventions with 5% and 14% discount rates

	5%			14%		
	Cost	Benefit	BCR	Cost	Benefit	BCR
Full BEmONC	34,221	562,949	16	21,262	290,481	14
Targeted BEmONC	14,074	472,071	34	8,818	243,348	28
Assisted vaginal delivery	6,343	129,473	20	4,005	66,822	17
KMC for premature babies	2,147	103,966	48	1,378	53,545	39
Hygienic cord care	3,495	118,450	34	2,160	61,005	28
Clean birth practices	6,885	94,958	14	4,398	48,996	11
Neonatal resuscitation	2,892	98,643	34	1,840	50,806	28

Source: Estimates by the authors

The Malawi Priorities Project